

**SEISMIC HAZARD ZONE REPORT FOR THE
DEL SUR 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

2005



DEPARTMENT OF CONSERVATION
California Geological Survey

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SEISMIC HAZARD ZONE REPORT 101

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DEL SUR 7.5-MINUTE QUADRANGLE,
LOS ANGELES COUNTY, CALIFORNIA**

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EXECUTIVE SUMMARY

This report and the accompanying Preliminary Seismic Hazard Zones Map for the Del Sur 7.5-Minute Quadrangle, Los Angeles County, California, are revisions of the original preliminary report and map that were released April 17, 2003. This report and map reflect required changes following the adoption of revised seismic hazard zone mapping criteria by the State Mining and Geology Board in April 2004. Accordingly, the 90-day period provided for public review is repeated, beginning on the release date noted on the revised Preliminary Seismic Hazard Zones map. The report summarizes the methods and sources of information used to prepare the accompanying seismic hazard zones map. The map displays the boundaries of zones of required investigation for liquefaction and earthquake-induced landslides over an area of approximately 62 square miles at a scale of 1 inch = 2,000 feet.

The Del Sur Quadrangle lies in northern Los Angeles County along the boundary between the mountains and Antelope Valley about 11 miles west of Lancaster and 44 miles north of the Los Angeles Civic Center. The San Andreas Rift Zone crosses the southwestern quarter of the quadrangle within Leona Valley. South of valley the mountains rise to 4,341 feet near the southwestern corner. Portal Ridge, with 400 to 600 feet of relief, separates Leona Valley from Antelope Valley. North of the ridge the California Aqueduct crosses the entire quadrangle. The eastern slopes of Antelope Buttes in the northwestern corner interrupt the gently sloping terrain of Antelope Valley. The lowest point is at 2,373 feet in the northeastern corner. A small area in the southwestern corner is within the Angeles National Forest. About one and one-half square miles of the southeastern corner is within the city of Palmdale. North of Avenue M and/or the California Aqueduct and east of 110th Street West most of the land is within the City of Lancaster. The remaining land is unincorporated Los Angeles County land. Land use in the quadrangle includes agriculture, ranching, and rural homes.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years.

In the Del Sur Quadrangle liquefaction zones coincide with Leona Valley and the narrow trough-like valley to the north, the bottoms of canyons, and within wash areas in Antelope Valley. The mountainous parts of the quadrangle are underlain by crystalline bedrock that is resistant to landsliding. However, some of the steepest slopes fall within an earthquake-induced landslide zone that covers about 3 percent of the quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the California Geological Survey's Internet page: <http://www.consrv.ca.gov/CGS/index.htm>

Paper copies of Official Seismic Hazard Zone Maps, released by CGS, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
945 Bryant Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at CGS offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

The Act directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria, which were published in 1992 as CGS Special Publication 118, were revised in 1996 and 2004. The Act also directed CGS to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

In April 2004, significant revisions of liquefaction zone mapping criteria relating to application of historically high ground-water level data in desert regions of the state were adopted by the SMGB. These modifications are reflected in the revised CGS Special Publication 118 (DOC, 2004), which is available on the Internet at: http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf

This report and the accompanying Preliminary Seismic Hazard Zones map incorporate the newly adopted criteria and replace the original preliminary report and map that were released in April 17, 2003. The report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic

mapping, ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10 percent probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Del Sur 7.5-Minute Quadrangle.

SECTION 1

LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Del Sur 7.5-Minute Quadrangle, Los Angeles County, California

**By
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**California Department of Conservation
California Geological Survey**

Note: In April 2004, significant revisions of liquefaction zone mapping criteria relating to application of historically high ground-water levels in desert regions of the state were adopted by the State Mining and Geology Board (SMGB). These changes are reflected in the revised CGS Special Publication 118 (DOC, 2004), which is available on the Internet at http://gmw.consrv.ca.gov/shmp/webdocs/sp118_revised.pdf

This report and the accompanying Preliminary Seismic Hazard Zones Map for the Del Sur Quadrangle, which are revisions of the original preliminary report and map released in April 17, 2003, incorporate the newly adopted zone mapping criteria.

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones.

Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (SMGB) (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing liquefaction hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of liquefaction analysis, evaluation, and mitigation techniques (SCEC, 1999). This text is also on the Internet at: <http://www.scec.org/>

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Del Sur 7.5-Minute Quadrangle. The section and the accompanying Preliminary Seismic Hazard Zones map are revisions of an earlier preliminary report and map released April 17, 2003. The changes, which affect liquefaction zonation in some high desert regions, were prompted by SMGB adoption of revised criteria in April 2004 (DOC, 2004).

Section 2 (addressing earthquake-induced landslides) and Section 3 (addressing potential ground shaking) complete the report, which is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on CGS's Internet web page: <http://www.consrv.ca.gov/CGS/index.htm>

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in southern California. During the 1971 San Fernando and 1994 Northridge earthquakes significant damage to roads, utility pipelines, buildings, and other structures in the Los Angeles area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions exist in parts of southern, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard in the southern California region in, including areas in the Del Sur Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Shallow ground-water maps were constructed
- Geotechnical data were quantitatively analyzed to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on CGS probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the SMGB (DOC, 2004).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years) sedimentary deposits. Such areas within the Del Sur Quadrangle consist mainly of the alluviated floors of Antelope Valley and Leona Valley. CGS's liquefaction hazard evaluations are based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth, which is gathered from various sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Del Sur Quadrangle covers about 62 square miles in northern Los Angeles County along the boundary between the mountains and Antelope Valley. The center of the area is 11 miles west of Lancaster and 44 miles north of the Los Angeles Civic Center. The northwest-trending San Andreas Rift Zone crosses the southwestern quarter of the quadrangle within Leona Valley, which is drained by Amargosa Creek. South of the rift zone the mountains rise to 4,341 feet near the southwestern corner of the quadrangle. Portal Ridge, which has 400 to 600 feet of relief, separates Leona Valley from the Antelope Valley. North of Portal Ridge the eastern slopes of Antelope Buttes interrupt the gently sloping terrain of Antelope Valley in the northwestern corner of the map area. The lowest point in the quadrangle is at 2,373 feet in the northeastern corner. The California Aqueduct crosses the entire quadrangle along the northern side of Portal Ridge.

Less than one-half square mile in the southwestern corner is within the Angeles National Forest. Approximately one and one-half square miles of land in the southeastern corner, south of Avenue M and east of 80th Street West, lies within the City of Palmdale. North of Avenue M and/or the California Aqueduct and east of 110th Street West most of the land is within the City of Lancaster. All of the remaining area is unincorporated Los Angeles County land. Land use in the quadrangle includes agriculture, ranching, and rural homes.

Access to the region is via Elizabeth Lake-Pine Canyon Road along Leona Valley. Johnson Road crosses Portal Ridge at the southern end of 110th Street West. A grid of east-west avenues (lettered) and north-south streets (numbered) covers the floor of Antelope Valley.

GEOLOGY

Bedrock and Surficial Geology

Geologic units that are generally susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. For this evaluation, the Quaternary geologic map of Ponti and others (1981) was used for the Antelope Valley part of the quadrangle while mapping by Barrows and others (1985) was used for most of

the mountainous area along the San Andreas Fault Zone. The two maps were digitized by the Southern California Areal Mapping Project. In addition, a map by Dibblee (2002) was also used to fill in the southwestern corner of the quadrangle.

Plate 1.1 shows the generalized Quaternary geology of the Del Sur Quadrangle compiled from Ponti and others (1981) and, for convenience of scale, the generalized map of Dibblee (2002). As shown on Plate 1.1, approximately 80 percent of the quadrangle is covered by alluvial deposits of Quaternary age. These Pleistocene through Holocene surficial deposits are summarized in Table 1.1 and discussed below. The remaining area consists of Mesozoic granitic rocks exposed on Antelope Buttes and pre-Quaternary sedimentary, granitic, and metamorphic rocks exposed in the southern part of the quadrangle. The bedrock units are discussed in the earthquake-induced landslide portion (Section 2) of this report.

Ponti and others (1981) mapped the Quaternary units based mainly on relative age (Q1-Q7; Q1 being oldest) and grain size (f=fine, m=medium, and c=coarse). Barrows and others (1985) divided Quaternary deposits mainly on the basis of age or environment of deposition. For example, older alluvium is Qoa and younger alluvium is Qal or stream channel deposits are Qsc and alluvial fan deposits are Qf. In the Del Sur Quadrangle Dibblee (2002) mapped Quaternary deposits simply on the basis of older (Qoa) and younger (Qa) deposits.

The oldest Quaternary unit mapped by Ponti and others (1981) consists of weakly consolidated, uplifted and moderately to severely dissected Pleistocene alluvial fan deposits (Q1, Q2, Q3). These deposits occur in the southern and western part of the quadrangle along the base of the foothills. Soils on these materials are moderately to well developed with well-formed horizons and clay accumulations and are distinctly reddish-brown in color. B profile ranges from 50 cm in the youngest deposits (Q3) to 2 m in the oldest (Q1). The units are mapped largely on the basis of the distribution of three units, which progresses from no apparent relationship (Q1) to close relationship to present day topography and clast sources (Q3). Some unit pairs are undifferentiated (for example, Q1-2). Q1-Q3 are equivalent to the undifferentiated older Quaternary deposits (Qoa) of Dibblee (2002).

Much of the quadrangle is covered by late Pleistocene deposits (Q4). Ponti and others (1981) describe this unit along with Q5 as unconsolidated, uplifted, and slightly dissected alluvial fan deposits. The two units are grouped because of similarities in topographic expression and soil development. The exposed materials are generally coarse and have moderately developed soils and clay accumulations in B profiles that are less than 50 cm with sound, but oxidized, granitic clasts. Color ranges from medium to dark brown with occasional reddish-brown mottling in the older unit (Q4). Q4 and Q5 correlate with a variety of units mapped by Barrows and others (1985) as older alluvium and related surficial deposits. They are also equivalent to part of the deposits mapped as older Quaternary (Qoa) by Dibblee (2002).

Sediments mapped by Ponti and others (1981) as Quaternary playa deposits (Qpl) cover approximately 2 square miles of land in the western part of the quadrangle. Regionally,

these sediments are described as compact lacustrine silt and clay with minor loose well-sorted sand and fine gravel deposited in the shallow-water margins of the last pluvial lake that filled the lowland parts of Antelope valley up to about 12,000 years ago. This unit lies outside the areas mapped by Barrows and others (1985) and Dibblee (2002).

Latest Pleistocene to Holocene alluvial fan and wash sediments (Q6) exposed in the northeastern part of the quadrangle are unconsolidated, mainly sandy and silty sediments. Soils on these alluvial fan and colluvial materials are weakly developed. These sediments correlate closely in age with the sediments mapped as various younger alluvial and related surficial deposits by Barrows and others (1985) and Qa by Dibblee (2002) within Leona Valley in the southwestern part of the quadrangle.

A medium-grained sedimentary unit rich in secondary calcium carbonate (Quca) covers several square miles in the central and western area of the quadrangle. Ponti and others (1981) assume the parent materials to be equivalent to Q4, Q5, and Q6 sediments (late Pleistocene to Holocene). The unit, which can contain up to 50 percent calcium carbonate concretions and platy cemented layers, is considered by Ponti (1980) to have been affected by fluctuating ground-water levels during late Pleistocene and early Holocene time. In the Del Sur Quadrangle, the presence of calcium carbonate is usually limited to depths extending between 5 and 15 feet. Exposures of this unit also lie outside the areas mapped by Barrows and others (1985) and Dibblee (2002).

Map Unit			Environment of Deposition	Age
Ponti and others (1981)	Barrows and others (1985)	Dibblee (2002)		
Q6	Qal, Qf, Ql, Qsw, Qt	Qa	alluvial fan, wash, colluvial aprons	latest Pleistocene and Holocene
Quca	N/A	N/A	alluvial fan, with secondary carbonate	late Pleistocene and Holocene
Qpl	N/A	N/A	playa deposits	late Pleistocene and Holocene
Q4, Q5	Qoa, Qof, Qopo	Qoa	alluvial fan, wash, colluvial aprons	late Pleistocene
Q1, Q2, Q3	Qof	Qoa	alluvial fan, wash, colluvial aprons	late Pleistocene

Table 1.1. Map Units Used in the Del Sur 7.5-Minute Quadrangle

Structural Geology

About 75 percent of the Del Sur Quadrangle is within the Antelope Valley, a wedge-shaped part of the Mojave Desert bounded on the northwest by the Garlock Fault and the Tehachapi Mountains, and on the south by the San Andreas Fault and the Transverse

Ranges. The remaining area lies within mountainous terrain. A four-mile segment of the San Andreas Rift cuts across the southwestern corner of the quadrangle. This segment includes traces that ruptured during the great 1857 Fort Tejon earthquake and many mapped fault strands have been included in the Official Earthquake Fault Zone prepared by CDMG (1979) (now CGS) and considered to be a major potential seismic source (Petersen and others, 1996).

ENGINEERING GEOLOGY

As stated above, soils that are generally susceptible to liquefaction are mainly late Quaternary alluvial and fluvial sedimentary deposits and artificial fill. Deposits that contain saturated loose sandy and silty soils are most susceptible to liquefaction. Lithologic descriptions and soil test results reported in geotechnical borehole logs provide valuable information regarding subsurface geology, ground-water levels, and the engineering characteristics of sedimentary deposits.

Of particular value in liquefaction evaluations are logs that report the results of downhole standard penetration tests. Standard Penetration Tests (SPTs) provide a uniform measure of the penetration resistance of geologic deposits and are commonly used as an index of soil density. This in-field test consists of counting the number of blows required to drive a split-spoon sampler (1.375-inch inside diameter) one foot into the soil at the bottom of a borehole at chosen intervals while drilling. The driving force is provided by dropping a 140-pound hammer weight 30 inches. The SPT method is formally defined and specified by the American Society for Testing and Materials (2004) in test method D1586. Recorded blow counts for non-SPT geotechnical sampling where the sampler diameter, hammer weight or drop distance differ from those specified for an SPT (ASTM D1586), are converted to SPT-equivalent blow counts. The actual and converted SPT blow counts are normalized to a common-reference effective-overburden pressure of one atmosphere (approximately one ton per square foot) and a hammer efficiency of 60 percent using a method described by Seed and Idriss (1982) and Seed and others (1985). This normalized blow count is referred to as $(N_1)_{60}$.

The Seed-Idriss Simplified Procedure for liquefaction evaluation was developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant amount of gravel. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils presumably would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes, and recent laboratory studies have shown that gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. They are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have

been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

During the initial stages of this investigation, CGS obtained logs of geotechnical boreholes that had been drilled in various localities within Antelope Valley. Staff collected the logs from the files of the cities of Lancaster and Palmdale, California Department of Transportation, Los Angeles County Public Works Department, and Earth Systems, Inc. Only four of the logs collected are from boreholes drilled within the Del Sur Quadrangle. The drill sites were digitally located and associated log data entered into the CGS geotechnical GIS database to enable computer-assisted analysis and evaluation.

Examination of borehole logs indicate that throughout the Del Sur Quadrangle sedimentary deposits at depths of less than 40 feet are composed predominantly of loose to moderately dense sandy and silty sediments, even within the area mapped by Ponti and others (1981) as lacustrine playa deposits (see Geology section). The lithologic descriptions provided in geotechnical borehole logs were augmented by examination of lithologic descriptions included in the logs of scores of water wells drilled in the study area.

Geologic Map Unit	Material Type	Consistency	Age	Liquefaction Susceptibility*
stream channel, wash (Qsc)	medium to coarse sand and gravel	very loose	latest Holocene	high
sand dune (Qsd)	sand	very loose	Holocene & late Pleistocene	high
overbank, sheet flood (Q7)	sand, gravel, & silt	loose	Holocene & late Pleistocene	high
alluvial fan, overbank, sheet flood (Q6)	sand, gravel, & silt	loose to dense	Holocene & late Pleistocene	high to moderate
alluvial fan w/ secondary carbonate (Quca)	sand and silt w/ up to 10' thick zone of calcium carbonate cement	loose to very dense	Holocene & late Pleistocene	high to low
playa deposits (Qpl)	sand, silt, clay	loose to dense	Holocene & late Pleistocene	high to low
alluvial fan (Q4)	gravel, sand, silt, clay	dense	Pleistocene	low
alluvial fan (Q3)	gravel, sand, silt, clay	dense	Pleistocene	low

*when saturated

Table 1.2. Quaternary Map Units Used in the Del Sur 7.5-Minute Quadrangle and Their Geotechnical Characteristics and Liquefaction Susceptibility

GROUND WATER

Saturation reduces the effective normal stress of near-surface sediment, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). CGS compiles and interprets ground-water data to identify areas characterized by, or anticipated to have in the future, near-surface saturated soils. For purposes of seismic hazard zonation, "near-surface" means at a depth less than 40 feet.

Natural hydrologic processes and human activities can cause ground-water levels to fluctuate over time. Therefore, it is impossible to predict depths to saturated soils during future earthquakes. One method of addressing time-variable depths to saturated soils is to establish an anticipated high ground-water level based on historical ground-water data. In areas where ground water is either currently near-surface or could return to near-surface levels within a land-use planning interval of 50 years, CGS constructs regional contour maps that depict these levels. In some areas with low precipitation, such as Antelope Valley, records may indicate that near-surface ground water existed during historical time, but large withdrawal and low recharge rates preclude a return to those conditions within 50 years. For these areas, the historically highest ground-water level is not used to establish the anticipated depth to saturated soil for hazard evaluation. For these and all other areas, CGS delineates present or anticipated near-surface saturated soils caused by locally perched water and seepage from surface-water bodies.

Future initiation of large-scale, artificial recharge programs could result in a significant rise in ground-water levels over 50 years. When alerted of such programs, CGS will evaluate their impact relative to liquefaction potential and revise official seismic hazard zone maps, if necessary. Plate 1.2 depicts areas characterized by present or anticipated shallow ground water within the Del Sur Quadrangle.

Staff used the following publications and internet sources to evaluate ground-water conditions and historical ground-water use in the Del Sur and surrounding quadrangles: Johnson (1911); Thompson (1929); California Department of Water Resources (1965); Bloyd (1967); Durbin (1978); Duell (1987); Leighton and Associates (1990); Templin and others (1995); Galloway and others (1998); Carlson and others (1998); Carlson and Phillips (1998); Sneed and Galloway (2000); Los Angeles County Department of Public Works (2003); and California Department of Water Resources (2003). A detailed report of the ground-water hydrology of Antelope Valley is available on the U.S. Geological Survey web site (U.S. Geological Survey, 2003). In addition, satellite imagery provided by ASTER (2001) was used to identify and delineate major drainages and surface water bodies.

PART II

LIQUEFACTION POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. CGS's method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the SMGB (DOC, 2004).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

CGS's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10 percent probability of exceedance over a 50-year period (DOC, 2004). The earthquake magnitude used in CGS's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Del Sur Quadrangle, PGAs ranging from 0.43 to 0.88g, resulting from a predominant earthquake of magnitude 7.8, were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10 percent in 50-year hazard level (Petersen and others, 1996; Cramer and Petersen, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

CGS performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997; Youd and others, 2001). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, CGS's analysis uses the Idriss magnitude-scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: $FS = (CRR / CSR) * MSF$. FS, therefore, is a quantitative measure of liquefaction potential. CGS uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures.

The CGS liquefaction analysis program calculates an FS for each geotechnical sample where blow counts were collected. Typically, multiple samples are collected for each borehole. The program then independently calculates an FS for each non-clay layer that

includes at least one penetration test using the minimum $(N_1)_{60}$ value for that layer. The minimum FS value of the layers penetrated by the borehole is used to determine the liquefaction potential for each borehole location. The reliability of FS values varies according to the quality of the geotechnical data. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Three of the four geotechnical borehole logs reviewed in this study (Plate 1.2) include blow-count data from SPTs or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2½-inch inside-diameter ring samplers, are generally translated to SPT-equivalent values if reasonable factors can be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all of the information (for example, soil density, moisture content, sieve analysis, etc.) required for an ideal Seed-Idriss Simplified Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using averaged test values of similar materials.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the SMGB (DOC, 2004). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes
2. Areas of uncompacted fill that are saturated, nearly saturated, or may be expected to become saturated
3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable
4. Areas where existing subsurface data are not sufficient for quantitative evaluation of liquefaction hazard. Within such areas, zones may be delineated by geologic criteria as follows:
 - a) Areas containing soil deposits of late Holocene age (current river channels and their historical floodplains, marshes and estuaries) where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.10 g and the anticipated depth to saturated soil is less than 40 feet; or

- b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.20 g and the anticipated depth to saturated soil is less than 30 feet; or
- (c) Areas containing soil deposits of latest Pleistocene age (between 11,000 years and 15,000 years), where the M7.5-weighted peak acceleration that has a 10 percent probability of being exceeded in 50 years is greater than or equal to 0.30 g and the anticipated depth to saturated soil is less than 20 feet.

Application of these criteria allows compilation of liquefaction zones of required investigation, which are useful for preliminary evaluations, general land-use planning and delineation of special studies zones (Youd, 1991).

Areas of Past Liquefaction

Documentation of historical liquefaction or paleoseismic liquefaction in the Del Sur Quadrangle was not found during this study.

Artificial Fills

No artificial fill site large enough to show at the scale of mapping used in this report was identified in the Del Sur Quadrangle.

Areas with Sufficient Existing Geotechnical Data

Geotechnical borehole and water well data generally provide an adequate basis for evaluating liquefaction potential in the Leona Valley area of the Del Sur Quadrangle. Borehole log descriptions and geologic maps indicate that young Quaternary sedimentary layers deposited in Leona Valley include loose, sandy material that could liquefy where saturated within 40 feet of the surface, as shown on Plate 1.2. These areas are designated zones of required investigation on the Seismic Hazard Zone Map of the Del Sur Quadrangle.

Areas with Insufficient Existing Geotechnical Data

Staff depended significantly on SMGB Criterion Item 4 (see above) for zoning liquefaction in the Antelope Valley area of the Del Sur Quadrangle. Areas delineated are limited to washes draining the San Gabriel Mountains.

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REFERENCES

- American Society for Testing and Materials, 2004, Standard test method for penetration test and split-barrel sampling of soils, Test Method D1586-99, *in* Annual Book of ASTM Standards, v. 4.08.
- ASTER, (2001), <http://asterweb.jpl.nasa.gov/>
- Barrows, A.G., Kahle, J.E. and Beeby, D.J., 1985, Earthquake hazards and tectonic history of the San Andreas Fault Zone, Los Angeles County, California: California Division of Mines and Geology Open-File Report 85-10 LA, 236 p., 21 plates, map scale 1:12,000.
- Bloyd, R. M., Jr., 1967, Water resources of the Antelope Valley-East Kern Water Agency area, California: U.S. Geological Survey Open-File Report, 73 p.
- Budiman, J.S. and Mohammadi, Jamshid, 1995, Effect of large inclusions on liquefaction of sands, *in* Evans, M.D. and Frigaszy, R.J., *editors*, Static and Dynamic properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 48-63.
- California Department of Conservation, Division of Mines and Geology, 1979, Revised Official Map of Special Studies Zones, Del Sur Quadrangle, scale 1:24,000.
- California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: California Division of Mines and Geology Special Publication 117, 74 p.
- California Department of Conservation, Division of Mines and Geology, 2004, Recommended criteria for delineating seismic hazard zones in California: California Division of Mines and Geology Special Publication 118, 12 p.
- California Department of Water Resources, 1965, Water wells in the western part of the Antelope Valley Area, Los Angeles County, California: California Department of Water Resources Bulletin 91-11. *Prepared in cooperation with the U.S. Geological Survey.*

- California Department of Water Resources, 2003, Historical Data Map, Water Data Library: <http://wdl.water.ca.gov>
- Carlson, C.S. and Phillips, S.P., 1998, Water-level changes (1975-98) in the Antelope Valley, California: U.S. Geological Survey Open-File Report 98-561, 2 sheets.
- Carlson, C.S., Leighton, D.A., Phillips, S.P. and Metzger, L.F., 1998, Regional water table (1996) and water-table changes in the Antelope Valley ground-water basin, California: U.S. Geological Survey Water-Resources Investigations Report 98-4022, 2 sheets.
- Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange, and Ventura counties, California: Bulletin of Seismological Society of America, v. 86, no. 5, p. 1,645-1,649.
- Dibblee, T.W., Jr., 2002, Geologic map of the Lake Hughes and Del Sur quadrangles, Los Angeles County, California: Dibblee Geological Foundation Map DF-82, scale 1:24,000.
- Duell, L.F.W., Jr., 1987, Geohydrology of the Antelope Valley area, California, and design for a ground-water-quality monitoring network: U.S. Geological Survey Water-Resources Investigations Report 84-4081, 72 p.
- Durbin, T. J., 1978, Calibration of a mathematical model of the Antelope Valley ground-water basin, California: U.S. Geological Survey Water-Supply Paper 2046, 51 p. (*Prepared in cooperation with the California Department of Water Resources*).
- Evans, M.D. and Zhou, Shengping, 1995, Liquefaction behaviour of sand-gravel composites: American Society of Civil Engineers, Journal of Geotechnical Engineering, v. 121, no. 3, p. 287-298.
- Galloway, D.L., Phillips, S.P. and Ikehara, M.E., 1995, Land subsidence and its relation to past and future water supplies in Antelope Valley, California, *in* Borchers, J., *editor*, Land Subsidence--Case Studies and Current Research; Proceedings of the Dr. Joseph F. Poland Symposium on Land Subsidence: Association of Engineering Geologists Special Publication 8, p. 529-539.
- Harder, L.F. and Seed, H.B., 1986, Determination of penetration resistance for coarse-grained soils using the Becker hammer drill: University of California at Berkeley, College of Engineering, Earthquake Engineering Research Center, report no. UCB/EERC-86/06, 126 p.
- Ishihara, Kenji, 1985, Stability of natural deposits during earthquakes, *in* Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, San Francisco, v. 1, p. 321-376.
- Johnson, H.R., 1911, Water resources of Antelope Valley, California: U.S. Geological Survey Water-Supply Paper 278, 92 p.

- Leighton and Associates, 1990, Safety Element of the Los Angeles County General Plan, Hazard Reduction in Los Angeles County, volumes 1 and 2, Plate 4, scale 1:125,000.
- Los Angeles County Department of Public Works, 2003, Hydrologic reports 1996-2002 <http://ladpw.org/wrd/report/>
- National Research Council, 1985, Liquefaction of soils during earthquakes: National Research Council Special Publication, Committee on Earthquake Engineering, National Academy Press, Washington, D.C., 240 p.
- Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, Tianqing, Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.
- Ponti, D.J., 1980, Stratigraphy and engineering characteristics of upper Quaternary sediments in the eastern Antelope Valley and vicinity, California: M.S. Thesis, Stanford University, 157 p.
- Ponti, D.J., Burke, D.B. and Hedel, C.W., 1981, Map showing Quaternary geology of the central Antelope Valley and vicinity, California: U.S. Geological Survey Open-File Report 81-737, scale 1:62,500.
- Seed, H.B. and Idriss, I.M., 1971, Simplified procedure for evaluating soil liquefaction potential: Journal of the Soil Mechanics and Foundations Division of ASCE, v. 97: SM9, p. 1,249-1,273.
- Seed, H.B. and Idriss, I.M., 1982, Ground motions and soil liquefaction during earthquakes: Monograph Series, Earthquake Engineering Research Institute, Berkeley, California, 134 p.
- Seed, H.B., Idriss, I.M. and Arango, Ignacio, 1983, Evaluation of liquefaction potential using field performance data: Journal of Geotechnical Engineering, v. 109, no. 3, p. 458-482.
- Seed, H.B., Tokimatsu, Kohji, Harder, L.F., and Chung, R.M., 1985, Influence of SPT procedures in soil liquefaction resistance evaluations: Journal of Geotechnical Engineering, ASCE, v. 111, no. 12, p. 1,425-1,445.
- Seed, R.B. and Harder, L.F., 1990, SPT-based analysis of cyclic pore pressure generation and undrained residual strength: Proceedings of the H. Bolton Seed Memorial Symposium, v. 2, p. 351-376.
- Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: California Geology, v. 49, no. 6, p. 147-150.

- Sneed, M. and Galloway, D.L., 2000, Aquifer-system compaction and land subsidence; measurements, analyses, and simulations--the Holly Site, Edwards Air Force Base, Antelope Valley, California: U.S. Geological Survey Water-Resources Investigations Report 00-4015, 65 p.
- Southern California Earthquake Center, 1999, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating liquefaction in California: Southern California Earthquake Center, University of Southern California, 63 p.
- Sy, Alex, Campanella, R.G. and Stewart, R.A., 1995, BPT-SPT correlations for evaluations of liquefaction resistance in gravelly soils, *in* Evans, M.D. and Frigaszy, R.J., *editors*, Static and Dynamic Properties of Gravelly Soils: American Society of Civil Engineers Geotechnical Special Publication no. 56, p. 1-19.
- Templin, W.E., Phillips, S.P., Cherry, D.E., DeBortoli, M.L. and others, 1995, Land use and water use in the Antelope Valley, California: U.S. Geological Survey Water Investigations Report 94-4208, 98 p.
- Thompson, D.G., 1929, The Mohave Desert region, California, a geographic, geologic and hydrologic reconnaissance: U.S. Geological Survey Water-Supply Paper 578, 759 p.
- Tinsley, J.C., Youd, T.L., Perkins, D.M. and Chen, A.T.F., 1985, Evaluating liquefaction potential, *in* Ziony, J.I., *editor*, Evaluating earthquake hazards in the Los Angeles region — An earth science perspective: U.S. Geological Survey Professional Paper 1360, p. 263-316.
- U.S. Geological Survey, 2003, Ground Water Atlas of the United States – Segment 1 California Nevada, <http://ca.water.usgs.gov/groundwater/gwatlas/basin/single.html>
- Youd, T.L., 1973, Liquefaction, flow and associated ground failure: U.S. Geological Survey Circular 688, 12 p.
- Youd, T.L., 1991, Mapping of earthquake-induced liquefaction for seismic zonation: Earthquake Engineering Research Institute, Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 111-138.
- Youd, T.L. and Idriss, I.M., 1997, *editors*, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: National Center for Earthquake Engineering Research Technical Report NCEER-97-0022, 276 p.
- Youd, T.L. and Perkins, D.M., 1978, Mapping liquefaction-induced ground failure potential: Journal of Geotechnical Engineering, v. 104, p. 433-446.
- Youd, T.L., Idriss, I.M., Andrus, R.D., Arango, I., Castro, G., Christian, J.T., Dobry, R., Finn, W.D.L., Harder, L.F. Jr., Hynes, M.E., Ishihara, K., Koester, J.P., Liao, S.S.C., Marcusson, W.F., Martin, G.R., Mitchell, J.K., Moriwaki, Y., Power, M.S.,

Robertson, P.K., Seed, R.B. and Stokoe K.H., 2001, Liquefaction resistance of soils: Summary report from the 1996 NCEER and 1998 NCEER/NFS workshops on evaluation of liquefaction resistance of soils, Journal of Geotechnical and Geoenvironmental Engineering, October 2001, pp 817-833.

SECTION 2

EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Del Sur 7.5-Minute Quadrangle, Los Angeles County, California

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California Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by CGS in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

Following the release of DMG Special Publication 117 (DOC, 1997), agencies in the Los Angeles metropolitan region sought more definitive guidance in the review of geotechnical investigations addressing landslide hazards. The agencies made their request through the Geotechnical Engineering Group of the Los Angeles Section of the American Society of Civil Engineers (ASCE). This group convened an implementation committee in 1998 under the auspices of the Southern California Earthquake Center (SCEC). The committee, which consisted of practicing geotechnical engineers and engineering geologists, released an overview of the practice of landslide analysis, evaluation, and mitigation techniques (SCEC, 2002). This text is also on the Internet at: <http://www.scec.org/>

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Del Sur 7.5-Minute Quadrangle. Section 1 (addressing liquefaction) and Section 3 (addressing earthquake shaking) complete the report, which is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: <http://www.consrv.ca.gov/CGS/index.htm>

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Del Sur Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared
- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area
- Seismological data in the form of CGS probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a CGS pilot study (McCrink and Real, 1996; McCrink, 2001) and adopted by the State Mining and Geology Board (DOC, 2004).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Del Sur Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Del Sur Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and

engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Del Sur Quadrangle covers about 62 square miles in northern Los Angeles County along the boundary between the mountains and Antelope Valley. The center of the area is 11 miles west of Lancaster and 44 miles north of the Los Angeles Civic Center. The northwest-trending San Andreas Rift Zone crosses the southwestern quarter of the quadrangle within Leona Valley, which is drained by Amargosa Creek. South of the rift zone the mountains rise to 4,341 feet near the southwestern corner of the quadrangle. Portal Ridge, which has 400 to 600 feet of relief, separates Leona Valley from the Antelope Valley. North of Portal Ridge the eastern slopes of Antelope Buttes in the northwestern corner interrupt the gently sloping terrain of Antelope Valley. The lowest point in the quadrangle is at 2,373 feet in the northeastern corner. The California Aqueduct crosses the entire quadrangle along the northern side of Portal Ridge.

Less than one-half square mile in the southwestern corner is within the Angeles National Forest. About one and one-half square miles in the southeastern corner, south of Avenue M and east of 80th Street West, lies within the City of Palmdale. North of Avenue M and/or the California Aqueduct and east of 110th Street West most of the land is within the City of Lancaster. All of the remaining area is unincorporated Los Angeles County land. Land use in the quadrangle includes agriculture, ranching, and rural homes.

Access to the southern map area is via Elizabeth Lake-Pine Canyon Road along Leona Valley. Johnson Road crosses Portal Ridge at the southern end of 110th Street West. A grid of east-west avenues (lettered) and north-south streets (numbered) covers the floor of Antelope Valley in the central and northern map areas.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface in the form of a digital topographic map. Within the Del Sur Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the U.S. Geological Survey (1993). This DEM, prepared from the 7.5-minute quadrangle topographic contours based on 1956 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map.

The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The geologic map used as background geology for the Del Sur Quadrangle was prepared from three sources. Ponti and others (1981) mapped the Quaternary geology of central Antelope Valley and vicinity, including the Del Sur Quadrangle. Detailed geologic maps of the San Andreas Fault Zone, including the segment that traverses the Del Sur Quadrangle, were prepared by Barrows and others (1985, Plates 1C and 1D). Geologic maps from both of these sources were digitized by the Southern California Areal Mapping Project [SCAMP]. The pre-Quaternary sedimentary, volcanic, and crystalline rocks are generalized on the Ponti and others (1981) map. Therefore, part of a geologic map by Dibblee (2002) was digitized by CGS for the southwestern corner of the quadrangle south of the detailed map by Barrows and others, along the fault zone. Bedrock units are described in detail in this section. Surficial geologic units are briefly described here and are discussed in more detail in Section 1, Liquefaction Evaluation Report.

CGS geologists modified the digital geologic map in the following ways. Landslide deposits were deleted from the map so that the distribution of bedrock formations and the newly created landslide inventory would exist on separate layers for the hazard analysis. Contacts between bedrock and surficial units were revised to better conform to the topographic contours of the U.S. Geological Survey 7.5-minute quadrangle. Air-photo interpretation, digital orthophoto quarter quadrangle photo review, and field reconnaissance was performed to assist in adjusting contacts between bedrock and surficial geologic units, between map sources, and to review geologic unit lithology and geologic structure.

Additionally, the digital geologic map was modified to include interpretations of observations made during the aerial photograph review for the landslide inventory and field reconnaissance. In the field, observations were made of exposures, aspects of weathering, and general surface expression of the geologic units. In addition, the relation of the various geologic units to the development and abundance of landslides was noted.

The San Andreas Fault, which traverses the lower half of the Del Sur Quadrangle from the southeast to the northwest, forms a significant tectonic boundary with dissimilar bedrock assemblages north of, within, and south of the fault zone.

North of and within the San Andreas Fault Zone

The oldest rock unit north of the main trace of the San Andreas Fault, is the pre-Cenozoic age Portal Schist (map symbol pos), which is well exposed on Portal Ridge. Portal Schist predominantly consists of medium gray, fine- to coarse-grained quartzo-feldspathic and

dark biotite schist, with common marble and quartzite layers and abundant vein quartz (Barrows and others, 1985). This bedrock weathers as tan to light brown grus, and the biotite-rich rocks are readily weathered along the foliation where exposed. In the vicinity of Johnson Road the Hitchbrook Fault separates the Portal Schist from a body of granodiorite and gneissic granodiorite (gd) that extends for 16 miles to the west along the northern side of the San Andreas Fault. The granodiorite unit is white to grayish white, fine to medium grained, massive to gneissic rock that ranges in composition from quartz monzonite to quartz diorite and is locally intruded by aplite and pegmatite dikes. Similar rocks are exposed at Antelope Buttes, in the northwest corner of the map area, where they were designated quartz monzonite to granodiorite (qm) by Dibblee (2002). Near the eastern boundary of the quadrangle, Dibblee (2002) mapped massive light-colored granite to quartz monzonite (gr) in fault contact with Portal Schist (psp). Ponti and others (1981) mapped all of the pre-Tertiary rocks as gr-m.

Exposed among interlacing fault strands within the San Andreas Fault Zone are several members of the non-marine Pliocene Anaverde Formation. These include the red arkose, buff arkose, clay shale, and breccia members (Barrows and others, 1985). The red arkose member (Tar) is a pink to red, medium-to thick-bedded, locally massive, coarse pebbly arkose. The buff arkose (Tab) is a buff to gray, medium-bedded to massive, medium- to very coarse-grained pebbly arkose with thin silty interbeds near the top. The clay shale member (Tac) is a gray to brown, thin-bedded, sandy, silty, locally very gypsiferous clay shale with interbedded siltstone and sandstone layers. The breccia member (Tabx) is a distinctive, reddish to dark gray, massive, pervasively sheared sedimentary breccia with angular clasts of hornblende diorite. The bedding within the Anaverde Formation members mostly parallels the bounding faults, and has steep to vertical dips.

In the remaining central and northern map area, north of Portal Ridge (Ponti and others, 1981), the upper Quaternary alluvial and colluvial units are designated by numbers (higher numbers signify more recent deposits) and letters, that signify coarseness of the materials (c being coarse- and m being medium-grained). In the Del Sur Quadrangle these units include Q2c, Q2-3c, Q3c, Q4m, Q4c, Q5c, Q5m, Q6m, Q6c, Q7c, and Q7c.

In addition, in the northeastern corner of the quadrangle, Ponti and others (1981) mapped deposits of compact alluvial materials around pluvial lake shorelines (Quca) and lacustrine silt and clay deposits (Qpl) associated with the late Pleistocene pluvial lake that occupied a large part of western Antelope Valley. In places, older and younger alluvial deposits cover the pre-Quaternary rocks of Portal Ridge and the San Andreas Fault Zone (Barrows and others, 1985). Older alluvium with Portal Schist clasts (Qopo) is unconsolidated, poorly sorted, moderately dissected fluvial gravel, sand, and silt deposits that are found close to the San Andreas Fault Zone and within Leona Valley. Older fan deposits (Qof), which are highly variable in texture and composition and occur above modern erosional surfaces, are also scattered in the fault zone. Younger alluvial units include fan deposits (Qf), slope wash (Qsw), lake deposits (Ql), and alluvium (Qal).

South of the San Andreas Fault

The bedrock south of the fault consists entirely of pre-Tertiary gneissic diorite and granodiorite exposed in the mountainous terrain south of Leona Valley. These rocks were mapped as a gneiss complex (dgn) of dark gray to black and white igneous, meta-igneous and metasedimentary rocks, migmatite, gneissic diorite, quartz diorite and granodiorite (Barrows and others, 1985). Map unit dgn is typically deeply weathered, commonly sheared and shattered, and rarely yields debris coarser than small pebbles. In the portion of the quadrangle compiled from the geologic map by Dibblee (2002) rocks of the gneissic diorite complex were mapped as quartz diorite (qd).

On the slopes south of Leona Valley, Barrows and others (1985) mapped older fan deposits (Qof). Dibblee (2002) mapped similar deposits as older surficial sediments composed of sand and gravel (Qoa). Younger units include fan deposits (Qf) and alluvium (Qal; Qa of Dibblee, 2002).

Structural Geology

The dominant structural feature in the quadrangle is the San Andreas Fault Zone that crosses the quadrangle and separates geologic terranes with dissimilar rock assemblages across the fault zone. Topographically, the San Andreas Fault lies within a linear, trough-like valley called the San Andreas Rift Zone. On the north, Portal Ridge borders the zone. The west-trending Hitchbrook Fault, which diverges from the San Andreas Fault west of the Del Sur Quadrangle, separates the Portal Schist on the east, from the granodiorite and gneissic granodiorite of Portal Ridge. The San Andreas Fault is the southwestern boundary of the Mojave block geomorphic province of California. The San Andreas Fault is considered to be an active seismic source (CDMG, 1997), and in the Del Sur Quadrangle, this fault is mapped with an Official Earthquake Fault Zone designation along the fault zone trace (CDMG, 1979).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Del Sur Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs, digital orthophoto quarter quadrangle photos, and a review of previously published landslide mapping (Barrows and others, 1985). Landslides were mapped at a scale of 1:24,000. For each landslide included on the map a number of characteristics (attributes) were compiled. These characteristics include the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the landslide zoning as described later in this report. Landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence. The completed landslide map was scanned, digitized, and the attributes were compiled in a database. A version of this landslide inventory is included with Plate 2.1.

Landslides are mapped mainly within the San Andreas Fault Zone and vicinity, and occur mostly within the steeply dipping Anaverde Formation. Landslides generally range from

minor surficial failures resulting from soil and rock creep, to moderate-size earth and debris slumps.

In addition to the mapped landslides, conspicuous linear depressions were observed along the top of Portal Ridge in air photos as well as in the field. These linear features may not be landslide related, but are expressed as closed depressions that may have a lateral spreading sense of movement. These ridge-tops lineaments and others parallel to them were mapped by Evans (1966) and are indicated on his map as faults. These features are included in this landslide inventory as questionable lateral spreading features for this study.

Because it is not within the scope of the Act to review and monitor grading practices to ensure past slope failures have been properly mitigated, all documented slope failures, whether or not surface expression currently exists, are included in the landslide inventory.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the units identified on the Del Sur Quadrangle geologic map was obtained from the County of Los Angeles- Public Works Department (see Appendix A). The locations of rock and soil samples taken for shear testing within the Del Sur Quadrangle are shown on Plate 2.1. Shear tests from the adjoining Lake Hughes and Sleepy Valley quadrangles were used to augment data for several geologic formations for which little or no shear test information was available within the Del Sur Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average ϕ) and lithologic character. Average (mean or median) ϕ values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups (Table 2.2) in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Table 2.1 and Table 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

Existing Landslides

As discussed later in this report, the criteria for landslide zone mapping state that all existing landslides that are mapped as definite or probable are automatically included in the landslide zone of required investigation. Therefore, an evaluation of shear strength parameters for existing landslides is not necessary for the preparation of the zone map. However, in the interest of completeness for the material strength map, to provide

relevant material strength information to project plan reviewers, and to allow for future revisions of our zone mapping procedures, we have collected and compiled shear strength data considered representative of existing landslides within the quadrangle.

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount of information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, have also been used.

SHEAR STRENGTH GROUPS								
	Formation Name	Number Tests	Mean/Median Phi	Mean/Median (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	qd ^{1*} qm ^{2*}	83						40
GROUP 2	psp ^{3*}	13						34
GROUP 3	Qa ⁴ af ^{5*} , Tas ^{5*} , Tab ^{6*}	76	29/30		29/30	-		29
GROUP 4	Qls*							16

qd¹ = dgn, gn
 qm² = gd, gr-m
 psp³ = pos, sch
 Qa⁴ = **original data**, Qf, Ql, Qoa, Qof, Qpa, Qsw, Qt, Q1-2c, Q2-3c, Q2c, Q3c, Q4c, Q4m, Q5c, Q5m, Q6c, Q6m, Q7c, Qdc, Qpl, Quca
 Tas⁵ = Tabx, Tac, Tar, gr-bx, grbx
 Tab⁶ = Qopo
 * = shear strength data of formations listed are taken from adjacent and near by Lake Hughes, Sleepy Valley, Agua Dulce, and Ritter Ridge Quadrangles.
 Formations for strength groups from Dibblee (2002), Barrows and others (1985), and Ponti and others (1981)

Table 2.1. Summary of the Shear Strength Statistics for the Del Sur Quadrangle.

SHEAR STRENGTH GROUPS FOR THE DEL SUR 7.5-MINUTE QUADRANGLE			
GROUP 1	GROUP 2	GROUP 3	GROUP 4
qd, qm	psp	af, Qa, Tas, Tab	Qls

Table 2.2. Summary of Shear Strength Groups for the Del Sur Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity.” For the Del Sur Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by CGS for a 10 percent probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	7.8
Modal Distance:	2.5 to 14.8 km
PGA:	0.46 to 0.9 g

The strong-motion record selected for the slope stability analysis in the Del Sur Quadrangle was the Southern California Edison Lucerne record from the 1992 magnitude 7.3 Landers, California, earthquake. This record had a source to recording site distance of 1.1 km and a peak ground acceleration (PGA) of 0.80g. Although the distance and parameter of the Lucerne record does not fall within the range of the probabilistic parameters, this record was considered to be sufficiently conservative to be used in the stability analyses. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

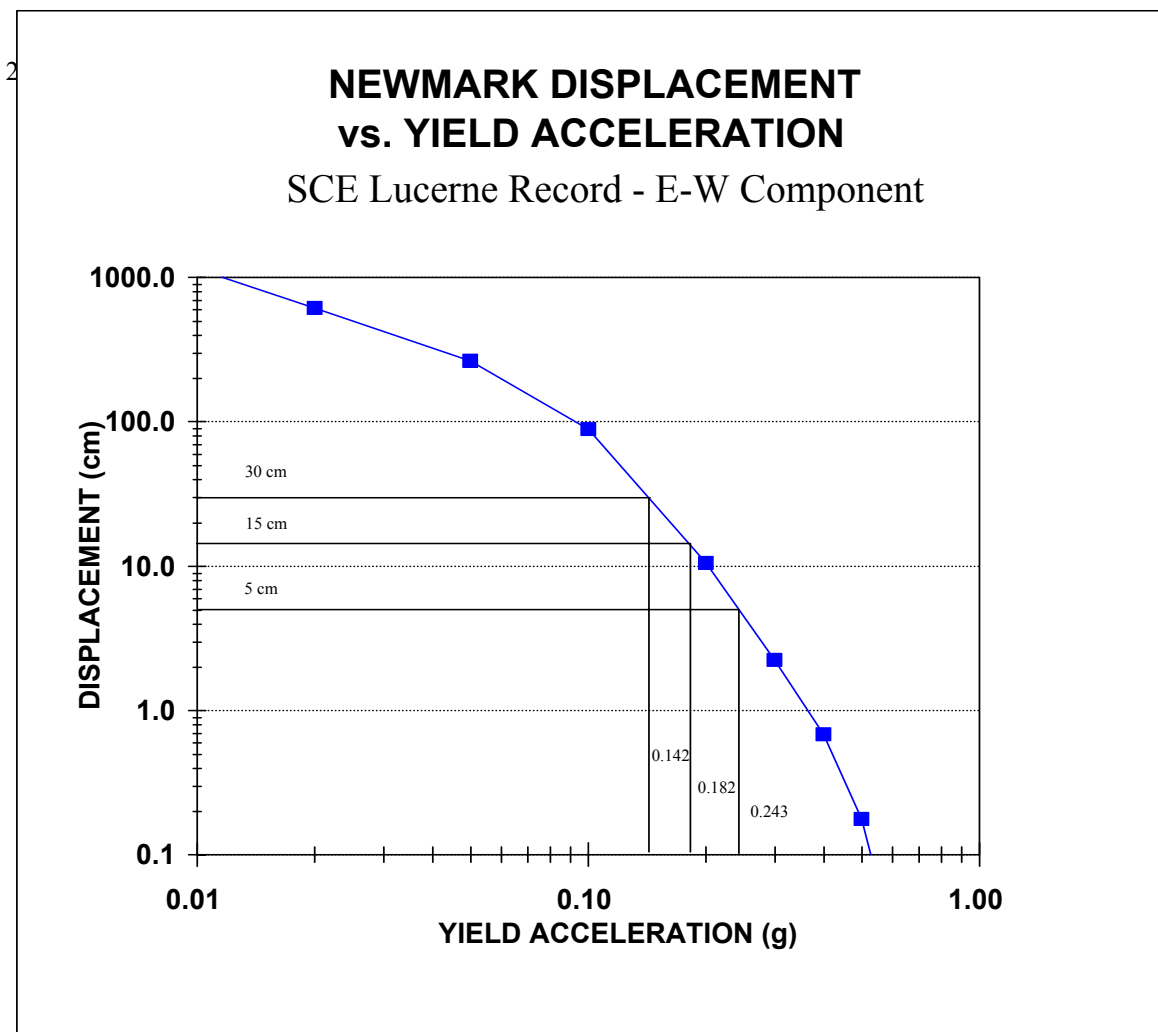


Figure 2.1. Yield Acceleration vs. Newmark Displacement for the Lucerne Record.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a CGS pilot study for earthquake-induced landslides (McCrink and Real, 1996; McCrink, 2001). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.24, 0.18 and 0.14g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Del Sur Quadrangle.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where **FS** is the Factor of Safety, **g** is the acceleration due to gravity, and **α** is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure **α** is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.14g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned.
2. If the calculated yield acceleration fell between 0.18g and 0.14g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned.
3. If the calculated yield acceleration fell between 0.24 and 0.18g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned.
4. If the calculated yield acceleration was greater than 0.24g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned.

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

DEL SUR QUADRANGLE HAZARD POTENTIAL MATRIX				
Geologic Material Strength Group (Average Phi)	HAZARD POTENTIAL (Percent Slope)			
	Very Low	Low	Moderate	High
1 (40)	0 to 56 %	56 to 61 %	61 to 66 %	>66 %
2 (34)	0 to 41 %	41 to 48 %	48 to 52 %	>52 %
3 (29)	0 to 29 %	29 to 35 %	35 to 39 %	>39 %
4 (16)	0 to 4 %	4 to 9 %	9 to 14 %	>14 %

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Del Sur Quadrangle. Values in the table show the range of slope gradient (expressed as percent slope) corresponding to calculated Newmark displacement ranges from the design earthquake for each material strength group.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2004). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.
2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer,

1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, **all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.**

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by CGS (McCrink and Real, 1996; McCrink, 2001), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 4 is included for all slopes steeper than 4 percent.
2. Geologic Strength Group 3 is included for all slopes steeper than 29 percent.
3. Geologic Strength Group 2 is included for all slopes steeper than 41 percent.
4. Geologic Strength Group 1 is included for all slopes greater than 56 percent.

This results in approximately three percent of the quadrangle lying within the earthquake-induced landslide hazard zone for the Del Sur Quadrangle.

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REFERENCES

- Barrows, A.G., Kahle, J.E. and Beeby, D.J., 1985, Earthquake hazards and tectonic history of the San Andreas Fault Zone, Los Angeles County, California: California Division of Mines and Geology Open-File Report 85-10 LA, 236 p., 21 plates, map scale 1:12,000.
- California Department of Conservation, Division of Mines and Geology, 1979, Earthquake Fault Zone Map Del Sur Quadrangle: Revised Official Map, Effective January 1, 1979.
- California Department of Conservation, Division of Mines and Geology, 1997 and 1999, Fault rupture hazard zones in California: Division of Mines and Geology Special Publication 42, supplements 1 and 2 added 1999, 38 p.
- California Department of Conservation, Division of Mines and Geology, 1997, Guidelines for evaluating and mitigating seismic hazards in California: Division of Mines and Geology Special Publication 117, 74 p.
- California Department of Conservation, Division of Mines and Geology, 2004, Recommended criteria for delineating seismic hazard zones, Division of Mines and Geology Special Publication 118, 12 p.
- Dibblee, T.W., Jr., 2002, Geologic map of the Lake Hughes and Del Sur quadrangles, Los Angeles County, California: Dibblee Geological Foundation map DF-82, map scale 1:24,000.
- Evans, James G., 1966, Structural Analysis and Movements of the San Andreas Fault Zone near Palmdale, Southern California, Doctoral Dissertation – University of California, Los Angeles, map scale 1:12,000.
- Horn, B.K.P., 1981, Hill shading and the reflectance map: Proceedings of the IEEE, v. 69, no. 1, p. 14-47.
- Jibson, R.W., 1993, Predicting earthquake-induced landslide displacements using Newmark's sliding block analysis: Transportation Research Board, National Research Council, Transportation Research Record 1411, 17 p.
- Keefer, D.K., 1984, Landslides caused by earthquakes: Geological Society of America Bulletin, v. 95, no. 4, p. 406-421.
- McCrink, T.P., 2001, Mapping earthquake-induced landslide hazards in Santa Cruz County in Ferriz, H. and Anderson, R., *editors*, Engineering geology practice in northern California: California Geological Survey Bulletin 210 / Association of Engineering Geologists Special Publication 12, p.77-94.

- McCrink, T.P. and Real, C.R., 1996, Evaluation of the Newmark method for mapping earthquake-induced landslide hazards in the Laurel 7-1/2 Minute Quadrangle, Santa Cruz County, California: California Division of Mines and Geology Final Technical Report for U.S. Geological Survey Contract 143-93-G-2334, U.S. Geological Survey, Reston, Virginia, 31 p.
- Newmark, N.M., 1965, Effects of earthquakes on dams and embankments: *Geotechnique*, v. 15, no. 2, p. 139-160.
- Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Division of Mines and Geology, Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.
- Ponti, D.J., Burke, D.B. and Hedel, C.W., 1981, Map showing Quaternary geology of the central Antelope Valley and vicinity, California: U.S. Geological Survey Open-File Report 81-737, map scale 1:62,500.
- Smith, T.C., 1996, Preliminary maps of seismic hazard zones and draft guidelines for evaluating and mitigating seismic hazards: *California Geology*, v. 49, no. 6, p. 147-150.
- Southern California Earthquake Center, 2002, Recommended procedures for implementation of DMG Special Publication 117 guidelines for analyzing and mitigating landslide hazards in California: T.F. Blake, R.A. Hollingsworth, and J.P. Stewart, *editors*, Southern California Earthquake Center, University of Southern California, 108 p.
- Trifunac, M.D., Todorovska, M.I. and Ivanovic, S.S., 1994, A note on distribution of uncorrected peak ground accelerations during the Northridge, California earthquake of 17 January 1994: *Soil Dynamics and Earthquake Engineering*, v. 13, no. 3, p. 187-196.
- U.S. Geological Survey, 1993, Digital Elevation Models: National Mapping Program, Technical Instructions, Data Users Guide 5, 48 p.
- Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, earthquake: *Bulletin of the Seismological Society of America*, v. 73, p. 863-877.
- Youd, T.L., 1980, Ground failure displacement and earthquake damage to buildings: American Society of Civil Engineers Conference on Civil Engineering and Nuclear Power, 2d, Knoxville, Tennessee, 1980, v. 2, p. 7-6-2 to 7-6-26.

AIR PHOTOS

Department of County Engineers, Soil Survey Los Angeles County, photo numbers; 1-6 through 1-13 and 1-84 through 1-89, dated 3-25-68 and 3-35 through 3-42, dated 3-28-68-137 through 5-134 dated 4-4-68, scale 1:24,000.

I.K. Curtis Services, Inc., Burbank, CA, photo numbers; 8195 through 8201, dated 6/24/1971, scale 1:12,000.

I.K. Curtis Services, Inc., Burbank, CA, color, photo numbers; 850 through 857, dated 3/5/1974, scale 1:12,000.

I.K. Curtis Services, Inc., Burbank, CA, photo numbers; 2252 through 2265, dated 3/31/1974, scale 1:6,000.

Digital Orthophoto Quarter Quadrangle Photos, dated 6/1/94, entire quadrangle area, Del Sur Quadrangle. (DOQQ and information concerning them can be obtained at <http://www-wmc.wr.usgs.gov/doq/>)

APPENDIX A SOURCE OF ROCK STRENGTH DATA

SOURCE	NUMBER OF TESTS SELECTED
Lake Hughes Quadrangle	57
Sleepy Valley Quadrangle	29
Agua Dulce Quadrangle	5
Ritter Ridge Quadrangle	69
Los Angeles County Department of Public Works	12
Total Number of Shear Tests	172

SECTION 3

GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Del Sur 7.5-Minute Quadrangle, Los Angeles County, California

By

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PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) [now called California Geological Survey (CGS)] to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997). The text of this report is on the Internet at <http://gmw.consrv.ca.gov/shmp/webdocs/sp117.pdf>

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided

herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions *for the analysis of ground failure* according to the "Simple Prescribed Parameter Value" method (SPPV) described in the site investigation guidelines (DOC, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on the California Geological Survey's Internet page: <http://www.consrv.ca.gov/CGS/index.htm>

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology [California Geological Survey], and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10 percent probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

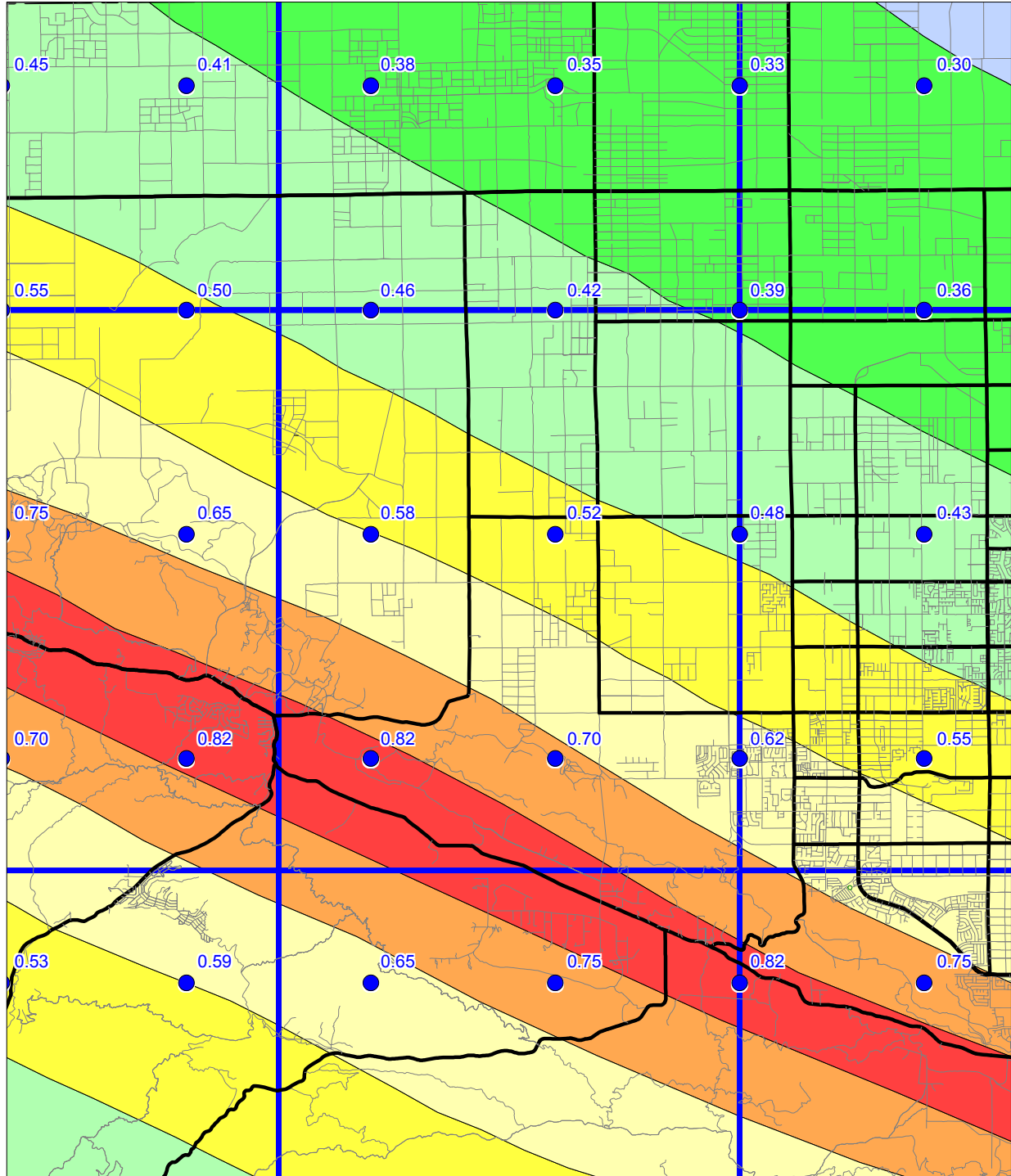
The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10 percent probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight

**SEISMIC HAZARD EVALUATION OF THE DEL SUR QUADRANGLE
DEL SUR 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES**

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.1

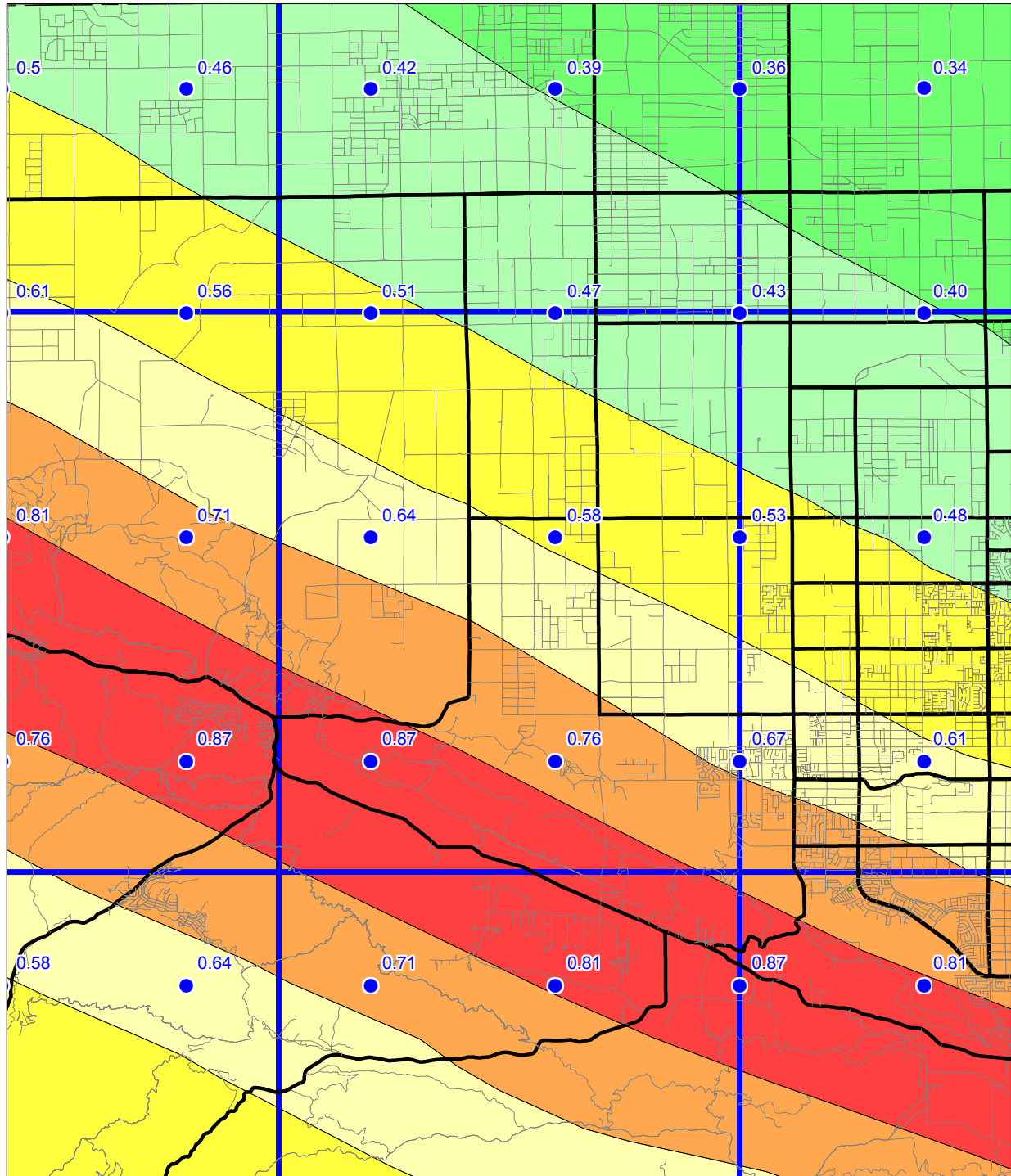


SEISMIC HAZARD EVALUATION OF THE DEL SUR QUADRANGLE
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1998

SOFT ROCK CONDITIONS



Base map from GDT

0 1.5 3
Miles

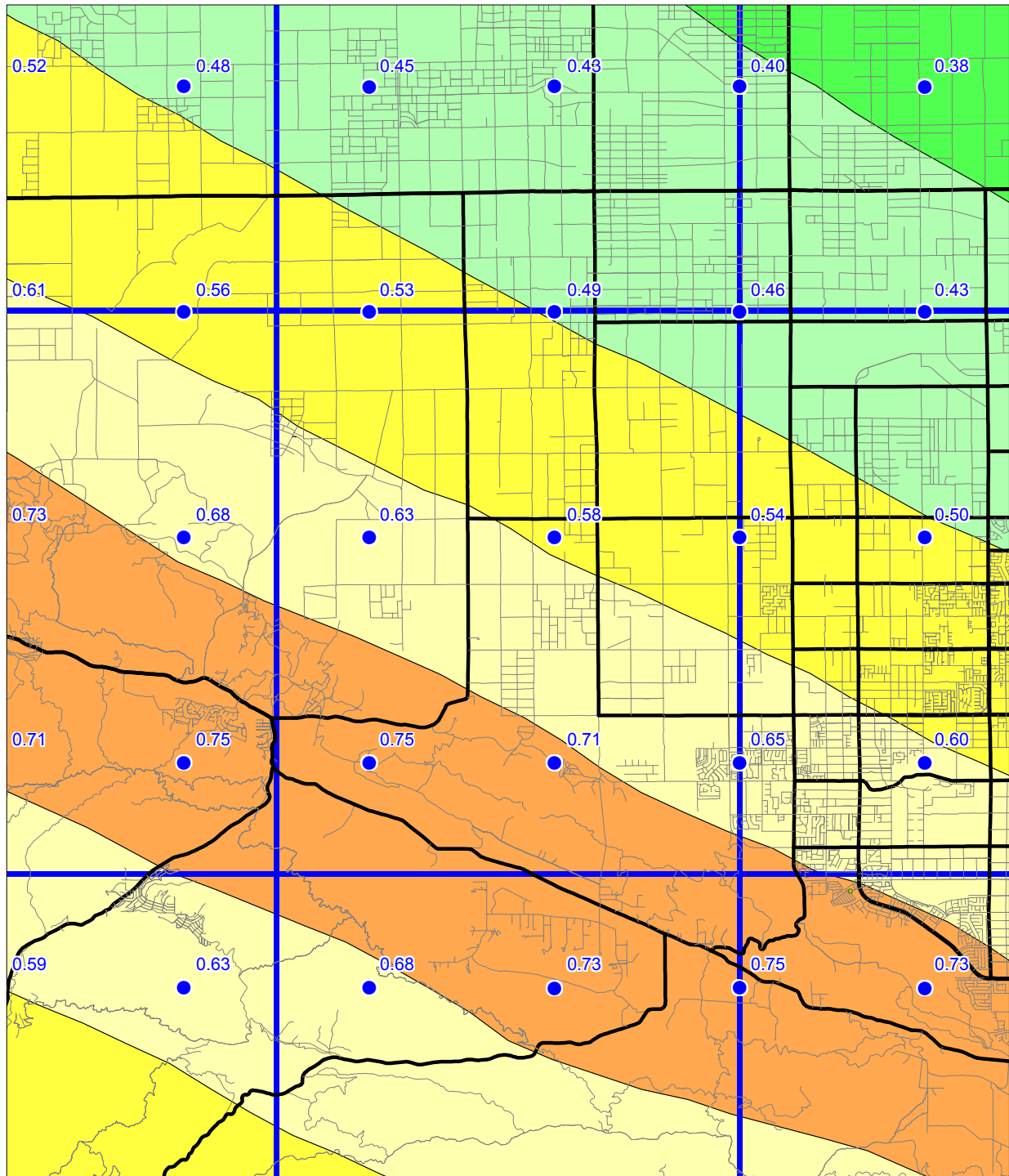
Department of Conservation
California Geological Survey

Figure 3.2



DEL SUR 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)
1998

ALLUVIUM CONDITIONS



Base map from GDT

0 1.5 3
MilesDepartment of Conservation
California Geological Survey

Figure 3.3



adjacent quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10 percent probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

A preferred method of using the probabilistic seismic hazard model and the “simplified Seed-Idriss method” of assessing liquefaction hazard is to apply magnitude scaling probabilistically while calculating peak ground acceleration for alluvium. The result is a “magnitude-weighted” ground motion (liquefaction opportunity) map that can be used directly in the calculation of the cyclic stress ratio threshold for liquefaction and for estimating the factor of safety against liquefaction (Youd and Idriss, 1997). This can provide a better estimate of liquefaction hazard than use of predominate magnitude described above, because all magnitudes contributing to the estimate are used to weight the probabilistic calculation of peak ground acceleration (Real and others, 2000). Thus, large distant earthquakes that occur less frequently but contribute *more* to the liquefaction hazard are appropriately accounted for.

Figure 3.5 shows the magnitude-weighted alluvial PGA based on Idriss’ weighting function (Youd and Idriss, 1997). It is important to note that the values obtained from this map are pseudo-accelerations and should be used in the formula for factor of safety without any magnitude-scaling (a factor of 1) applied.

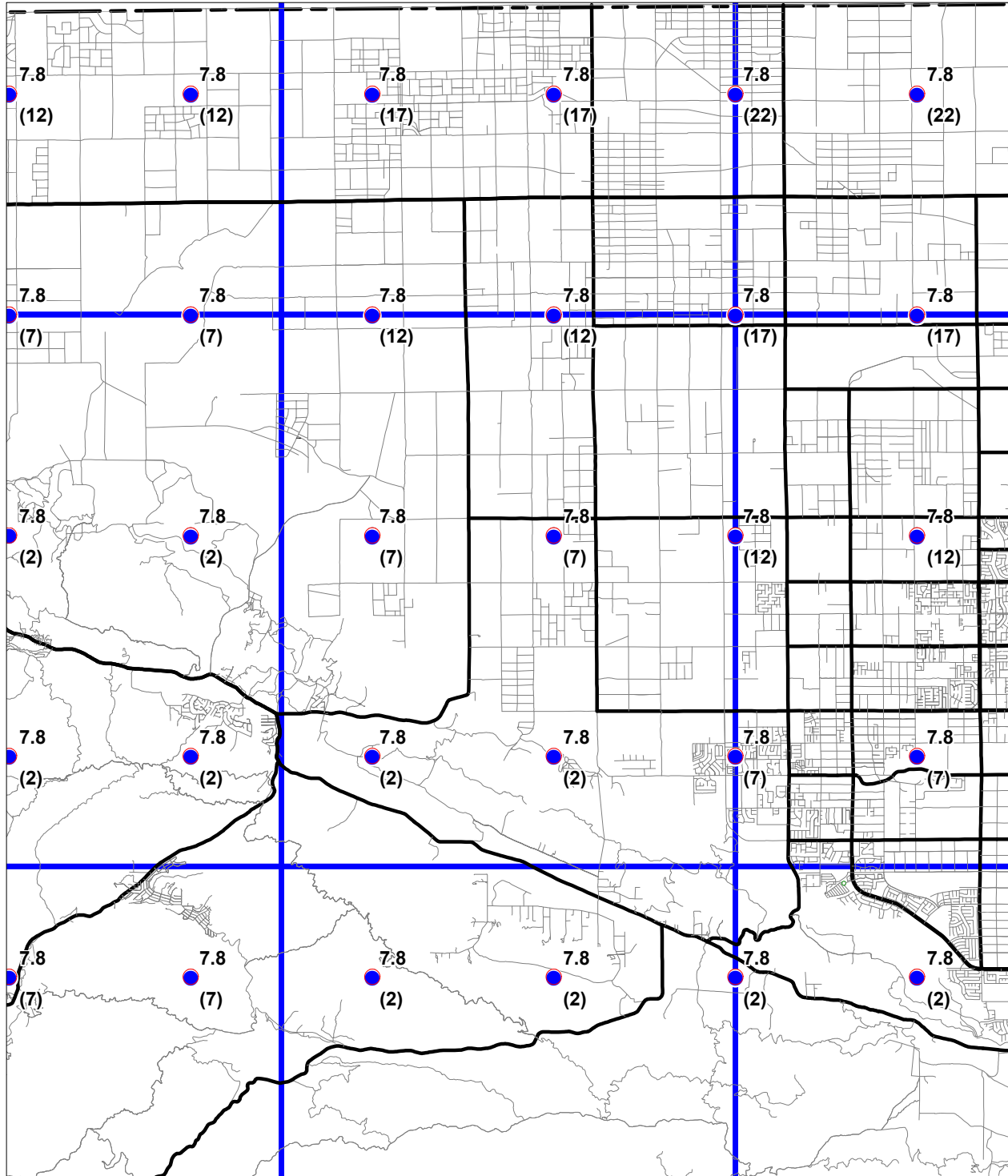
SEISMIC HAZARD EVALUATION OF THE DEL SUR QUADRANGLE
DEL SUR 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

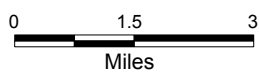
1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)
(Distance (km))



Base map from GDT



Department of Conservation
 California Geological Survey

Figure 3.4

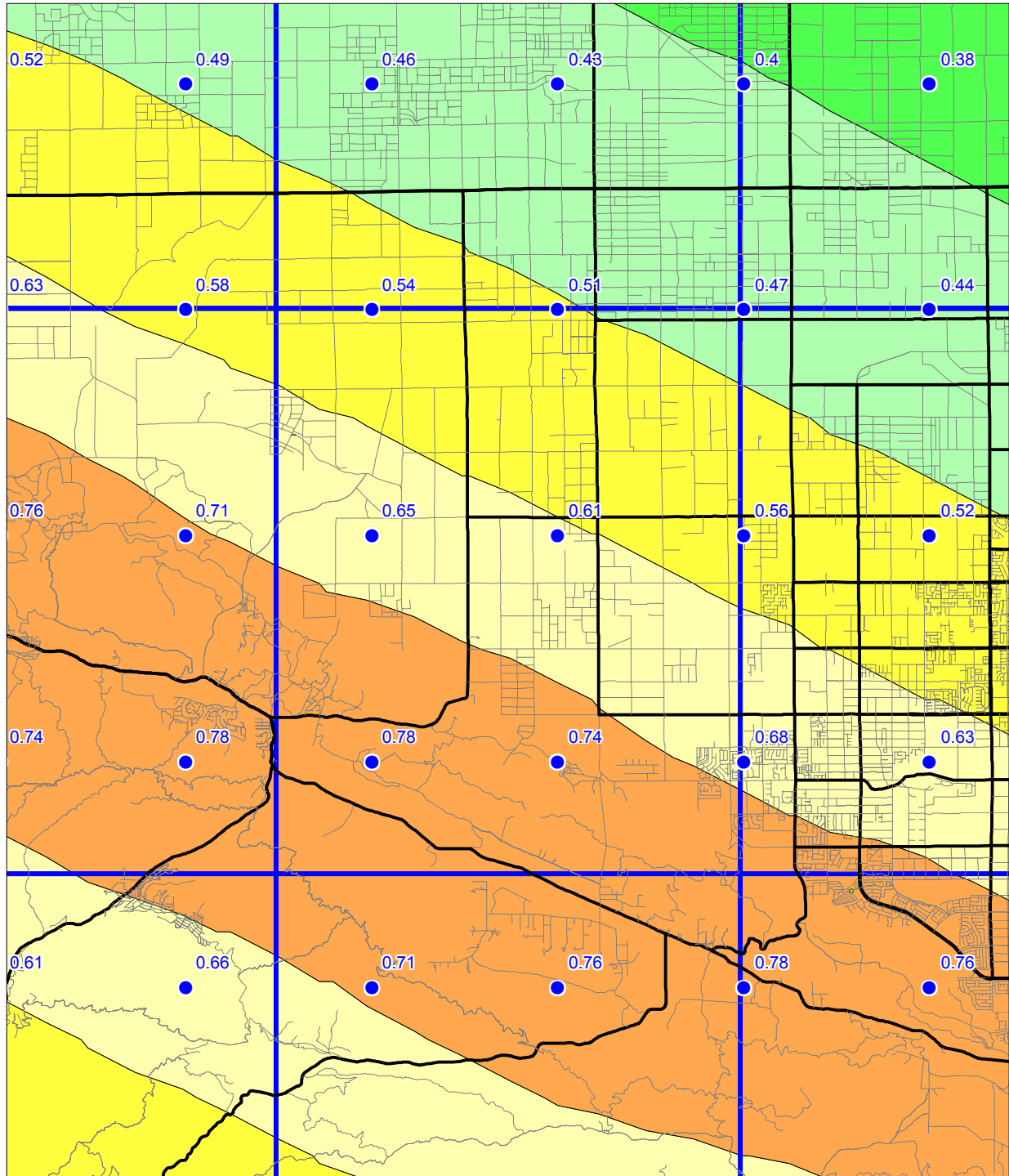


**SEISMIC HAZARD EVALUATION OF THE DEL SUR QUADRANGLE
DEL SUR 7.5 MINUTE QUADRANGLE AND PORTIONS OF
ADJACENT QUADRANGLES**

*10% EXCEEDANCE IN 50 YEARS MAGNITUDE-WEIGHTED PSEUDO-PEAK ACCELERATION (g)
FOR ALLUVIUM*

1998

LIQUEFACTION OPPORTUNITY



Base map from GDT

0 1.5 3
Miles

Department of Conservation
California Geological Survey

Figure 3.5



USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.
2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours.*
3. Uncertainties in the hazard values have been estimated to be about +/- 50 percent of the ground motion value at two standard deviations (Cramer and others, 1996).
4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.
5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the

recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

REFERENCES

- Boore, D.M., Joyner, W.B. and Fumal, T.E., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: *Seismological Research Letters*, v. 68, p. 154-179.
- California Department of Conservation, Division of Mines and Geology, 1997, *Guidelines for evaluating and mitigating seismic hazards in California: Special Publication 117*, 74 p.
- Campbell, K.W., 1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: *Seismological Research Letters*, v. 68, p. 180-189.
- Cramer, C.H. and Petersen, M.D., 1996, Predominant seismic source distance and magnitude maps for Los Angeles, Orange and Ventura counties, California: *Bulletin of the Seismological Society of America*, v. 85, no. 5, p. 1645-1649.
- Cramer, C.H., Petersen, M.D. and Reichle, M.S., 1996, A Monte Carlo approach in estimating uncertainty for a seismic hazard assessment of Los Angeles, Ventura, and Orange counties, California: *Bulletin of the Seismological Society of America*, v. 86, p. 1681-1691.
- International Conference of Building Officials (ICBO), 1997, *Uniform Building Code: v. 2, Structural engineering and installation standards*, 492 p.
- Jennings, C.W., *compiler*, 1994, *Fault activity map of California and adjacent areas: California Department of Conservation, Division of Mines and Geology, California Geologic Data Map Series, map no. 8.*
- Petersen, M.D., Bryant, W.A., Cramer, C.H., Cao, T., Reichle, M.S., Frankel, A.D., Lienkaemper, J.J., McCrory, P.A. and Schwartz, D.P., 1996, Probabilistic seismic hazard assessment for the State of California: California Department of Conservation, Division of Mines and Geology Open-File Report 96-08; also U.S. Geological Survey Open-File Report 96-706, 33 p.

- Real, C.R., Petersen, M.D., McCrink, T.P. and Cramer, C.H., 2000, Seismic Hazard Deaggregation in zoning earthquake-induced ground failures in southern California: Proceedings of the Sixth International Conference on Seismic Zonation, November 12-15, Palm Springs, California, EERI, Oakland, CA.
- Sadigh, K., Chang, C.-Y., Egan, J.A., Makdisi, F. and Youngs, R.R., 1997, SEA96- A new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, p. 190-198.
- Wilson, R.C. and Keefer, D.K., 1983, Dynamic analysis of a slope failure from the 1979 Coyote Lake, California, Earthquake: Bulletin of the Seismological Society of America, v. 73, p. 863-877.
- Youd, T.L. and Idriss I.M., 1997, Proceedings of the NCEER workshop on evaluation of liquefaction resistance of soils: Technical Report NCEER-97-0022, 40 p.
- Youngs, R.R., Chiou, S.-J., Silva, W.J. and Humphrey, J.R., 1997, Stochastic point-source modeling of ground motions in the Cascadia Region: Seismological Research Letters, v. 68, p. 74-85.

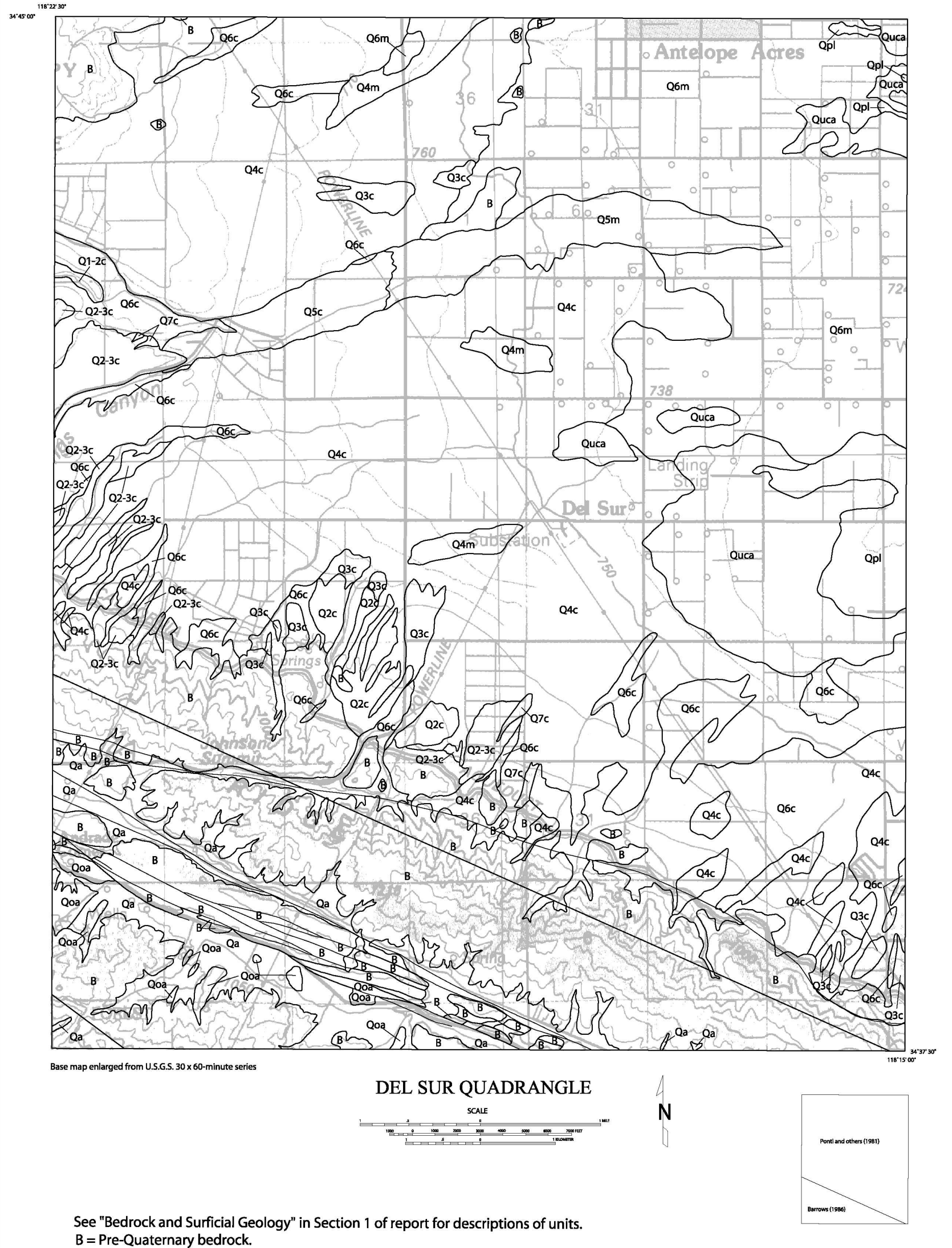
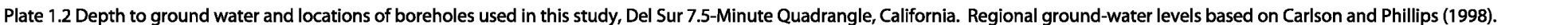


Plate 1.1 Quaternary Geologic Map of the Del Sur 7.5-Minute Quadrangle. Modified from Ponti and others (1981) and Barrows (1986).



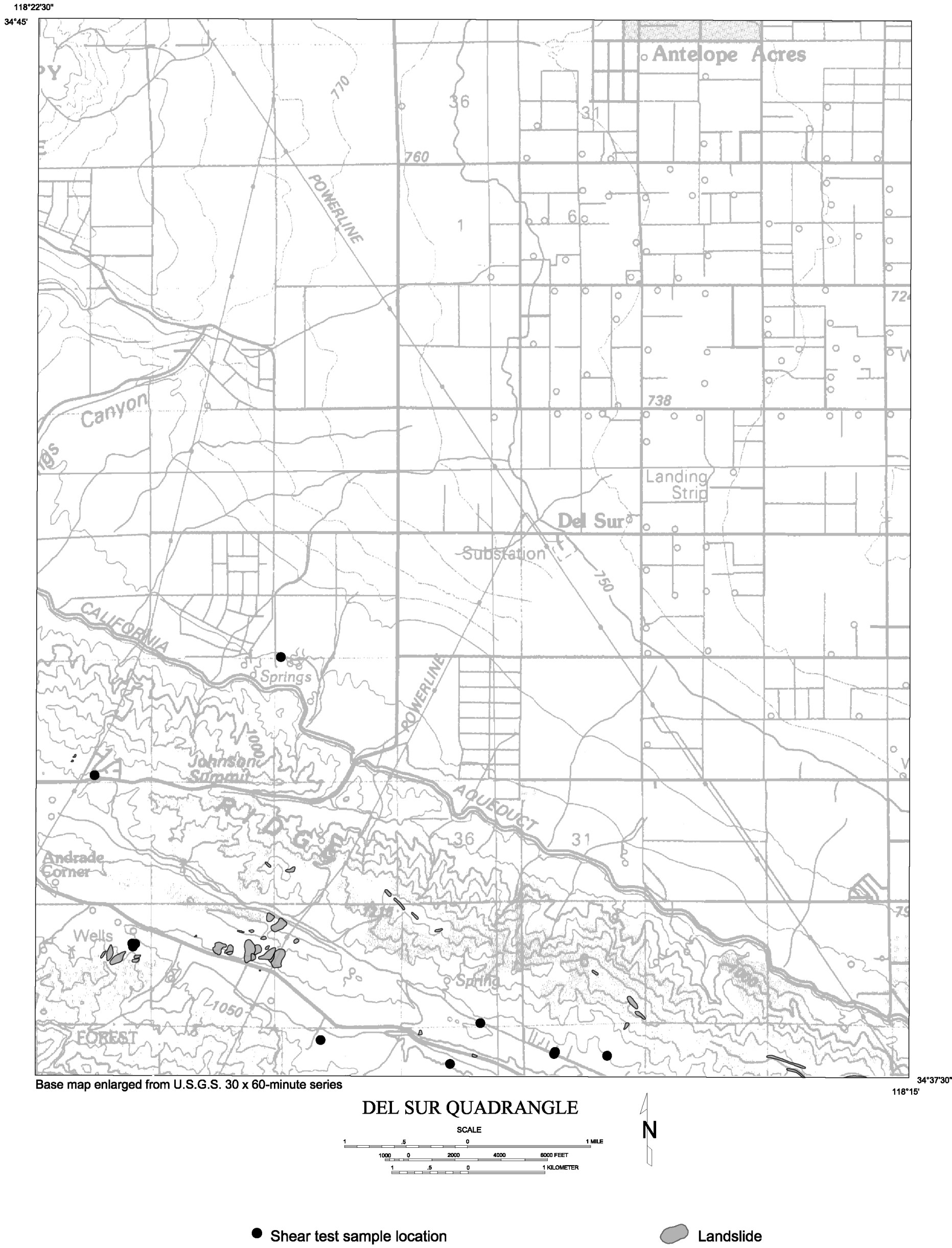


Plate 2.1 Landslide inventory, shear test sample locations, Del Sur 7.5-Minute Quadrangle, California.